ONR Initiatives Grant

David L. Hall
Applied Research Laboratory
The Pennsylvania State University
P. O. Box 30
Room 228, ARL Building
State College, PA 16804-0030
phone: (814) 863-4155 fax (814) 865-3105 email: dlh28@psu.edu
Awared #: N00014-96-1-0245
http://www.arl.psu.edu

LONG-TERM GOAL

The ONR Initiatives grant is aimed at supporting basic research initiatives to the U. S. Navy. These initiatives encourage interaction between Penn State's Applied Research Laboratory (ARL) researchers, Penn State faculty members, and provide opportunities for student research. During 1998, the ONR Initiatives program included five research projects and a High School Student Intern Program.

OBJECTIVES

Figure 1: Objectives of FY 98 ONR Initiatives Projects

Project	Focus/Objectives	Key Investigators
Turbulent effects on sound propagation	Extend investigations of sound propagation in a complex, turbulent atmosphere to the electromagnetic domain	K. E. Gilbert D. H. Werner J. D. Wyngaard
Turbulent flows over rough walls	Continue research in modeling and experimental data collection related to fluid flow near rough surfaces (for realistic Reynolds numbers)	T. R. Govidan S. Deutsch
Micro-scale heat exchangers and pumps	Continue a project initiated in FY 97 to design, model, and fabricate a microscale power source	D. H. Kiely R. J. Davis T. F. Miller J. H. Pickering
Coordination science	Continue a project initiated in FY 97 to investigate technology for effective coordination of large scale endeavors such as design of complex systems	S. Phoha E. Eberbach E. Peluso
Non-lethal technologies	New project to investigate key technologies related to non-lethal defense	D. L. Hall J. H. Shelton
High school intern Program	Summer enrichment program for high school students to encourage orientation for science and engineering	G. Lesieutre

APPROACH

Turbulent Effects on Sound Propagation - This effort investigated electromagnetic (EM) wave propagation through a realistic, turbulent atmosphere that includes both large-scale deterministic features (.1 ≈1000 km) as well as smaller scale, stochastic turbulent features (1 – 100 m). Collaborating

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **ONR Initiative Grant**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Pennsylvania State University,Applied Research Laboratory,PO Box 30,State College,PA,16804**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

with faculty from the Penn State Meteorology Department, refractivity fields, required to calculate propagation, were generated. The EM propagation was computed using a parabolic equation model.

Turbulent Flows over Rough Walls - The treatment of flow over rough surfaces requires knowledge of the effects of the height of the surface roughness elements as well as the type of surface roughness. Some experimental studies have involved flow measurements due to single grains of roughness and others have involved flow over rough surfaces coated with sand grains. Available experimental data indicates a need for a more general rough surface that accounts for the height and shape of roughness elements. Condensed matter physicists have recognized that rough surfaces can be described and constructed using fractal geometry. This approach has been investigated as the basis for scaling laws for the geometry of rough surfaces. The concept represents the actual rough surface with the statistically generated distribution of rough-surface elements.

Micro-scale Heat Exchangers and Pumps - This effort is aimed at developing a micro heat engine. Initially, a macro-scale heat source is being developed; development of a micro-scale heat source will follow. The development of a Rankine heat engine hinges on the successful development and integration of three key components: two-phase heat exchangers, an alternator/pump, and a turbine/alternator. A research group at MIT has designed a micro-turbine/alternator for producing electric work. The alternator is a rotating electrostatic generator. The MIT gas turbine/alternator originally developed for the air-breathing Brayton cycle, appears applicable to a Rankine cycle. Our research centers on the two remaining components: the two-phase heat exchangers, and the alternator/pump. This combination will also be useful as a very high flux heat sink.

Coordination Science - This research is developing fundamental techniques and associated computer technology to support greatly improved coordination in simulation-based design and acquisition of complex systems. In particular, a formal mode of the design network is being formulated as a finite set of interacting *autonoma*. Intelligent agents for design coordination and design supervision are introduced. The introduction of higher order polyadic process algebra allows the formulation of powerful algorithms for autonomous self-adaptation of the system design network to achieve high assurance specification in dynamic and uncertain environments. A Design Coordination Network (DCN) approach is being used to develop high assurance specification in dynamic and uncertain environments. An iterative refinement mechanism, for selecting component design characteristics and behavior coordination constraints, optimizes cooperative dynamic performance of system components.

Non-Lethal Technologies – One aspect of non-lethal technology is the capability for remote sensing and activation using coordinated semi-autonomous mobile devices (e.g., robots, aircraft, or underwater vehicles). Such networks allow remote monitoring of hostile environments and extension of human capabilities to support small unit operations. Examples include monitoring the dispersion of chemical and biological agents, perimeter surveillance, and mine detection. A key problem in such systems involves how to combine human in the loop control, with real-time semi-autonomous behavior by the mobile network nodes. This project has focused on the development of new techniques for hierarchical control of multiple systems with adaptation to a human in the loop.

WORK COMPLETED

Turbulent Effects on Sound Propagation - The investigation showed, for the first time, that the primary source for scattering of EM waves is the region at the top of the turbulent boundary layer where warm,

most air from below mixes with dry, cooler air from above. Since atmospheric moisture drives the index of refraction for EM waves the mixing of dry and moist air at the top of the boundary layer creates a region of intense refractivity fluctuations and, consequently, a region of strong scattering of EM waves. It was further discovered in the investigation that the standard horizontally-layered refractivity approximation ("plywood" approximation) over estimates the scattering by 15-20 dB compared to a realistic atmospheric model which has horizontal as well as vertical dependence. The initial results from the investigation have been published in a major EM symposium and the extended results are under review for publication in *Radio Science*. In addition, an article on the computational method has been submitted to *Radio Science* and is currently under review.

Turbulent Flow Over Rough Walls - Experiments were conducted initially with smooth walls to establish a detailed baseline data set for comparison with rough wall data. The experimental configuration is well documented with better-understood flow physics. The same is true for the computational modeling; hence, the effort has focused on detailed modeling of the smooth wall wind tunnel configuration. Tunnel geometry and limitations of the Laser Doppler Velocimetry (LDV) system dictated the experimental configuration. The setup involves flow in a rectangular duct with a more developed boundary layer on the vertical wall than on the horizontal wall. The entrance region leading into the rectangular test section uses a contraction on the vertical wall. This presented some difficulties with the turbulence models due to a very small unsteady separation at the duct entrance. However, this difficulty was overcome by replacing the contraction wall with a vertical flat surface. The appropriate upstream conditions were derived from an average velocity profile in the two-dimensional unsteady results for the actual vertical wall configuration. Further effort developed a suitable model for the forced transition of the laminar boundary layer on the walls. There are no experimental measurements in the transition region, so the effectiveness of the model was judged by examining two-dimensional boundary layer profiles downstream on both the vertical and horizontal walls where data is available. These comparisons were excellent and also matched the well-known laminar sublayer, buffer layer, and logarithmic regions of the axial velocity boundary-layer profile. These models have been extended to treat the three-dimensional representation of the experiment and preliminary runs are underway to verify the suitability of the smooth wall turbulence model to adequately reproduce the observed secondary flows in the corner of the duct.

Micro-scale Heat Exchanges and Pumps - The dominant heat transfer processes in two-phase flow is forced convection boiling. For macro-scale, this process has been well studied by academia and power production industries. Correlations for pressure drop and heat transfer are well established. While empirical, the form of these correlations typically derives from the underlying physics that dictate the boiling behavior when one operates with characteristic linear dimensions between 10 and 250 microns. For example, there may be insufficient nucleation sites on a silicon surface to produce sufficient roughness to guarantee macro-scale type nucleate boiling. Additionally, the flowfields at MEMS scales will be much lower than in macro-scale devices. Preliminary investigations of high flux boiling in both mini-channels and macro-channels have been conducted, focusing on the boiling regime characterized by the Critical Heat Flux (CHF) condition.

Coordination Science - Mathematical models and innovative analytical approaches were developed for the coordination of component behaviors to achieve high assurance of the integrated dynamical system. These results were published in four papers. A survey of related research efforts uncovered software being developed at Berkeley for automated coordination of component behavior from graphical models

of behavior interactions and constraints. This software has been acquired and will be used for further developments. Specific accomplishments include: (1) implementation of a general hierarchical architecture for design automation of complex dynamic systems; (2) development of a common message parsing language for behavior coordination of system components; and (3) creation of a syntax for automating computational intelligence for design refinement.

Non-Lethal Technologies - Various alternative architectural extensions to the ARL Intelligent Controller (IC) were explored. First, a uniform architecture for a hierarchical IC was developed using a fractal approach. This concept was extended for applications under control in the same way (i.e., an application under control at a lower level, when combined with the IC and the human at that level, becomes the application under control at the next higher level). Thus, the human-in-the-loop is an integral part of the system. Allowing a human to interact with an IC offered the opportunity to examine desirable IC capabilities. Two examples are allowing the IC to learn from human actions and allowing the IC to utilize prognostic simulations. Symmetrically, desirable human interactions with an IC were considered. For example, the ability to query the IC. By looking at various domains of application, additions were made to the list. The approach assumed a fixed application and an individual human-in-the-loop.

RESULTS

Figure 2: Summary of Results

Project	**Summary of Results**
Turbulent effects on sound propagation	Project completed. New mathematical models developed for sound propagation in turbulent atmospheric environments. The new models were validated using experimental data.
Turbulent flows over rough walls	On going project. New mathematical models developed for turbulent fluid flow over rough walls for both two-dimensional and three-dimensional cases. Test data collected in ARL Penn State water tunnel. Comparison of data and models on-going.
Micro-scale heat exchangers and pumps	On-going project. Design completed for a micro-scale heat engine, involving a high energy density heat source, micro-scale heat exchanger, and Rankine engine (very high-speed micro-turbine). Fabricated micro-scale heat exchanger at Penn State nano-fabrication facility.
Coordination science	On-going project. Developed new mathematical approach for coordination of component behaviors for complex systems to allow collaborative design. Began implementation of a Design Coordination Network (DCN) software environment.
Non-lethal technologies	New project. Developed a concept and approach for human in the loop control of a network of semi-autonomous robotic devices.

IMPACT/APPLICATIONS

Figure 3: Impact and Application of FY 98 Initiatives Projects

Project	Potential Impact	Example Applications
Turbulent effects on sounds propagation	Improved ability to predict sound propagation, leading to the ability to effectively use acoustic sensors	Internetted Unattended Ground Sensor (IUGS) systems;

Turbulent flows over rough walls	Significant improvements in modeling submarine and UAV maneuvers	Submarine maneuver prediction; design of fluid flow systems
Micro-scale heat exchangers and pumps	Compact, efficient and environmentally safe power sources for sensors, etc.	Remote sensor power sources; power for micro-scale UAVs
Coordination science	Improved ability for collaborative design of complex systems	Collaborative design of complex systems (e.g., torpedoes, new weapons platforms)
Non-lethal technologies	New ability to design and deploy networks of autonomous robotic devices with human-in-the-loop control	Remote sensing; support for small unit operations

TRANSITIONS

The research performed under this continuing project is integrated into the ARL Penn State on-going support to the U. S. Navy. Transition potentials include support to programs such as the DD-21, AAAV, the Joint Automated Maintenance Environment Accelerated Capability Technology Demonstration (ACTD), and related programs.

RELATED PROJECTS

Figure 4: Related Projects		
Related Projects	**Sponsor**	**Leverage/Relationship**
Ocean sampling mobile network	Office of Naval Research (ONR)	ONR Initiatives project provides the theoretical basis for practical demonstrations and applications of distributed design of complex systems and semi-autonomous robots
Mobile offshore base	ONR	

PUBLICATIONS

Kumar, R., Stover, J., “A behavior-based intelligent controller architecture”, *IEEE International Symposium on Intelligent Control*, Sept. 1998.

Kumar, R. Stover, J., Kiraly, A., “Discrete event modeling of a behavior-based intelligent control architecture”, *IEEE International Workshop on Intelligent Control*, Oct. 1998.

Phoha, S., Everbach, E., Peluso, E., Kiraly, A., “Coordination of engineering design agents for high assurance in complex dynamic system design”, Invited paper for a special track on High Assurance in Intelligent Systems, *3rd IEEE High Assurance Systems Engineering Symposium*, Washington, DC, Nov. 13, 1998

Phoha, S., Eberbach, E., Peluso, E., “Design coordination network for evolutionary integration of structural components of complex dynamical systems”, *Automoma*, Special issue on Control Methods for Communications Networks, Dec. 1999 (submitted)

Xiao D., Gilbert, K. E., Werner, D. H., “A fast Green’s function method for electromagnetic wave propagation in the atmosphere”, submitted to *Radio Science*, 1998.